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14. ABSTRACT
This TOP provides standardized tests recommended for evaluating hybrid vehicles. Because of the development of hybrid propulsion techniques for military wheeled and tracked vehicles new testing procedures to assess the automotive and safety design of these systems are required. This document provides a listing of and reference to pertinent existing TOPs recommended for that assessment. As hybrid specific test procedures are developed and validated through methodology testing, they will be added to the individual TOP listed.

15. SUBJECT TERMS

Hybrid vehicle	Current transducer	Voltage transducer
Motor generator	Traction battery	Traction motor
Resistance grid	Fuel consumption	Regenerative braking

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US ARMY DEVELOPMENTAL TEST COMMAND
TEST OPERATIONS PROCEDURE

Test Operations Procedure 2-1-003 — 08 December 2008
DTIC AD No.

HYBRID VEHICLES

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1. SCOPE.

This Test Operations Procedure (TOP) provides standardized tests recommended for evaluating hybrid vehicles. Because of the development of hybrid propulsion techniques for both military wheeled and tracked vehicles, new testing procedures to assess the automotive performance and safety design of these systems are required. This document provides a listing of and reference to pertinent existing TOPs recommended for that assessment. As hybrid specific test procedures are developed and validated through methodology testing, they will be added to the individual TOPs listed.

Extensive use of pertinent Society of Automotive Engineers (SAE) recommended practices and surface vehicle information reports were used as deemed practical in the development of this document. Additional documentation from EV America was also reviewed and pertinent portions of those documents were included for consideration when testing military vehicles. Specifically, much of the safety inspection process included in this document was obtained from the EV America, Hybrid Electric Vehicle Technical Specifications[1*].

2. FACILITIES AND INSTRUMENTATION.

Facilities and instrumentation are identified in the specific TOPs and International Test Operations Procedures (ITOPs) referenced within this TOP. In addition, the following facilities and instrumentation are specific to hybrid vehicle automotive testing.

2.1 Facilities.

Item	Requirements
Level Paved Road	A straight, level, paved road with a lane width of not less than 3.7 m, a longitudinal gradient ≤ 1%, and a side-to-side gradient ≤ 2%. Length of the roadway should be sufficient to allow the test vehicle, at its required payload condition, to accelerate to 96 km/hr (or maximum speed if lower than 96 km/hr) and then safely stop.
Level Cross Country	A level dirt course laid out in a loop with terrain of native soil that varies from moderately irregular to rough; e.g., Perryman Test Area (PTA) courses 2 and 3.
Hilly Course, Paved	Paved course with grades less than 11% that allows moderate to high road speeds; e.g., ATC's "Harford Loop".
Hilly Course, Off-road	Cross-country; moderate to rough native soil with grades less than 30%; e.g., Churchville Test Area (CTA) course B.
	Secondary; mix of improved gravel and paved roads with grades of 5 and 30%; e.g., Munson Test Area's standard fuel course.

[*] Superscript numbers correspond to those in Appendix D, References.

2.2 Instrumentation.

Devices for Measuring	Permissible Measurement Uncertainty (see Note 1)
Engine speed	1%
Voltage	1%
Current (bi-directional transducer)*	1%
Traction battery temperatures (ventilation, coolant, module (cell))	2°C

*Current sign conventions are as follow:

a. Current from the motor generator to the high voltage bus is positive (+).
b. Current from the traction battery to the high voltage bus is positive (+).
c. Current returned to the traction battery is negative (-).
d. Current used by the traction motor(s) for propulsion is negative (-).
e. Current generated by the traction motor(s) is positive (+).
f. Current to the resistive grid is negative (-).
g. All voltage measurements are positive (+).

Note 1: The permissible measurement uncertainty is the two-standard deviation value for normally distributed instrumentation calibration data. Thus 95% of all instrumentation calibration data readings will fall within two standard deviations from the known calibration value.

3. REQUIRED TEST CONDITIONS.

Test conditions for each procedure are identified in the TOPs and ITOPs referenced within this TOP.

The performance of a specific hybrid vehicle design may be affected by the traction battery state of charge (SOC) at the time of the test. This will be dependent on the driveline design, configuration, and operating duty cycle. For performance testing it is beneficial to evaluate the limits of performance. This will require repetition of many of the performance tests described in paragraph 4 at various states of charge. The process is an iterative one and extensive knowledge of the vehicle's control strategy as well as limitations of the various driveline components are necessary to make the proper selection of initial battery conditions.

Also, a means for altering the vehicle's initial SOC must be considered. The procedure may be as simple as operating the system in a "battery only" condition until the required SOC is achieved or as complex as gaining temporary access to the charging algorithms of the hybrid control or battery management system.

Hybrid vehicles may have multiple operating configurations which will depend on vehicle loading, environmental conditions and state of the secondary energy storage. The driveline control systems may also provide limits to protect components from overheating and/or overcharging. By working with the vehicle designers and system integrators a matrix of initial operating conditions should be developed so that a complete operational description of the vehicle can be developed. A typical matrix for a series hybrid electric vehicle may include the following:

Vehicle Configuration	Driveline Configuration	Battery State of Charge/Capacity
Gross Vehicle Weight (GVW)	Hybrid	High
		Low
	Silent Watch (Battery only)	High
		Low
	Engine only	High
		Low
Curb Weight	Hybrid	High
		Low
	Silent Watch (Battery only)	High
		Low
	Engine only	High
		Low

Specific definitions of descriptors like high and low SOC will need detailed clarification for each test conducted. If a quantitative value can be determined from a battery capacity measurement, for example, then that value should be used in lieu of a qualitative descriptor. Environmental conditions need to be accurately described in each test matrix. Hybrid vehicle performance may demonstrate significant variations in performance depending on ambient and battery module temperatures, control system limits, etc. Traction battery life should be captured for each test sequence as well. Installation dates, mileage driven, idle time, number of energy cycles are all appropriate measures for tracking battery life. Traction battery capacity, before and after each test sequence should also be presented, if available.

4. TEST PROCEDURES.

4.1 Vehicle Characteristics.

A listing of suggested vehicle characteristics are presented in TOP 2-2-500[2] and ITOP 2-2-500(1)[3].

Vehicle characteristics unique to hybrid vehicles include the following:

a. Driveline configuration: e.g., series or parallel hybrid.

b. Secondary energy source: e.g., battery, capacitor.

c. Nominal voltage of traction batteries.

d. Current and/or voltage limitations.

e. Number of cells, modules, batteries.

f. Configuration of cells, modules and battery strings.

g. Battery chemistry employed: e.g., lead-acid, lithium-ion, etc.

h. Procedure for measuring battery capacity.

i. Advertised battery capacity.

j. Energy density (actual and advertised).

k. Type/method of battery cooling and/or ventilation. For valve regulated batteries, the internal pressure level at which batteries vent should be specified.

l. Unique electrically driven accessories: e.g., steering assist, cooling pumps, ventilation fans, and powered turrets.

m. Power generation and propulsion motor characteristics.

Data are gathered from a variety of sources often depending on the maturity of the vehicle design and the technologies being employed. The test and evaluation team will need to rely on the vehicle builder and component suppliers for most initial information. Detailed vehicle and subsystem inspections will yield the characteristics of the driveline configuration and electrically driven accessories. Hybrid test vehicles should be plainly marked/placarded as such during the initial inspection process. The vehicle should be labeled “hybrid electric vehicle” and its nominal voltage should be stenciled in plain site.

Appendix C provides a glossary of terms specific to hybrid vehicles.

Appendix D provides a sample characteristic data sheet for the hybrid electric driveline and associated subsystems. This data sheet was taken from the EV America, Hybrid Electric Vehicle Technical Specifications.

4.2 Electrical Systems.

Determine the electrical requirements and capabilities of the vehicle subsystems in accordance with (IAW) TOP 2-2-601[4].

The battery capacity is one of the most important parameters of the hybrid propulsion system. Battery capacity influences long term vehicle performance as well as performance metrics such as acceleration, fuel consumption, gradeability and obstacle negotiation. Battery capacity is also the primary characteristic used to track battery health during the life of the test.

The battery capacity measurement and electrical load profile needs to be negotiated with the battery manufacturer, system integrator and/or vehicle builder. Suppliers should specify maximum normal and abnormal gassing rates for the battery pack. Suppliers should indicate the level of charge below which the batteries should not be discharged. This should include the specific parameters the battery management system utilizes to prevent over-discharge. At a minimum the Ampere-hours (Ah) rating(s), module voltage(s) and battery pack voltage(s) should be provided. The frequency of the battery capacity test should also be determined prior to the start of test. The battery chemistry, charging algorithms, self- protection limits and cell/module/battery arrangement require consideration in the development and implementation of the charge/discharge profile.

When measuring traction battery capacity, a means of safely and easily electrically isolating the traction batteries in the vehicle must be provided by the vehicle builder in order to conduct a battery capacity test. Isolation of the traction battery system should be measured IAW U.S. Department of Transportation National Highway Traffic Safety Administration Laboratory Test Procedure TP 305-00[5] Electric Powered Vehicles: Electrolyte Spillage and Electrical Shock Protection. This procedure was developed to evaluate the integrity of high-powered electrical system crashworthiness. The baseline measurements outlined in section 8.3 provide a means for measuring and evaluating the electrical isolation characteristics of high voltage power sources. SAE J1766[6], Recommended Practice for Electric and Hybrid Electric Vehicle Battery Systems Crash Integrity Testing, also provides isolation and measurement criteria.

Also, a means of connecting the traction batteries to an external bi-directional power supply must be provided. The discharge and charging profiles will be supplied using the external power source. The specific discharge and charging profiles should be supplied by the vehicle manufacturer. In the absence of a specific duty cycle SAE J1798[7], Recommended Practice for Performance Rating of Electric Vehicle Battery Modules, can be used to provide a generalized characterization of battery pack and module performance. The environmental conditions should be controlled as close to 25°C as practical. The testing location, date, time, and actual room temperature should be recorded for each test. Any deviation in ambient temperature should be noted. Concentrations of potential explosive gases in the battery box shall not be allowed to exceed 25% of the Lower Explosive Limit (LEL). Suppliers shall describe how battery boxes are vented, to allow any battery gases to escape safely to atmosphere during and following normal or abnormal charging and operation of the vehicle. Battery gas concentrations should be monitored in the occupant compartment. Vehicles shall not contain exposed conductors, terminals, contact blocks or devices of any type that create the potential for personnel to be exposed to 50 volts or greater. Access to any high voltage components should require the removal of at least one bolt, screw, or latch. Devices considered as high voltage components will be clearly marked as HIGH VOLTAGE. These markings should be installed at any point the voltage can be accessed by the end user. Additionally, cable and wire marking shall consist of orange wire and/or orange sleeving as identified in SAE J1127[8], Low Voltage Battery Cable.

Typically, the following data are provided for use in developing/implementing the battery capacity measurement:

a. *Rated capacity*: A designation by the battery manufacturer which identifies a particular traction battery configuration capacity. This definition generally provides an approximation of actual capacity. Rated capacity is usually expressed in ampere-hours (A-h) at a given discharge current.

b. *Discharge rate(s):* Amount of discharge current expressed as a function of time and/or voltage. This could be a combination of high and low rate discharge rates.

c. *Cut-off voltage:* Voltage at which a discharge or charge profile is terminated.

d. *In-rush current "fast charge":* Generally a high current applied for a short duration (< 1 hour) to initiate the charging cycle.

e. *Upper voltage limit:* Battery voltage where the current changes from a high rate to a low "topping" charge.

f. *Finishing current:* A reduced rate charge that completes (tops) the charge of a cell and can be continued in overcharge without damaging the cell/battery.

g. *Open circuit voltage:* The no-load voltage of a cell or battery measured with a high impedance voltmeter under constant environmental conditions.

Hardware/software capable of controlling predetermined voltage, current, and power limits with respect to time while discharging and charging the traction batteries, is required. Control of the voltage should be $\pm$200 mV or 0.15% of the output voltage. Current should be controlled to $\pm$250 mA or 0.25% of the current. The battery capacity is calculated by direct integration of the supplied current during the charging process (A-h) or from the calculated power with respect to time (kilowatt-hour (kW-h)).

4.3 Safety Evaluation.

Conduct testing to determine safety characteristics of the test vehicle and its components IAW TOP 2-2-508[9]. Checklists from TOP 10-2-508[10] are provided in Appendix B to provide guidance in developing safety inspections and testing.

SAE J2344[11], Guidelines for Electric Vehicle Safety, was used as a reference for identification and characterization of specific electrical vehicle safety hardware and design consideration. Electric and hybrid electric vehicles typically contain potentially hazardous levels of electrical voltage or current. It is important to protect the operators, maintainers and bystanders from exposure to this hazard. Under normal operating conditions, adequate electrical isolation is achieved through physical separation means such as the use of insulated wire, enclosures, or other barriers to direct contact. There are conditions or events that can occur outside normal operation that can cause this protection to be degraded. Some means should be provided to detect

degraded isolation or loss of separation, so that action can be taken to mitigate the problem. In addition, processes and/or hardware should be provided to allow for controlled access to the high-voltage system for instrumentation, maintenance or repair. A number of alternative means may be used to achieve these electrical safety goals, including automatic hazardous voltage disconnects, manual disconnects, interlock system(s), special tools, and grounding. A description of these methods is presented in the following paragraphs. The intention of all these means is either to prevent inadvertent contact with hazardous voltages or to prevent damage or injury from the uncontrolled release of electrical energy.

a. *Automatic Hazardous Voltage Disconnect*: Automatic hazardous voltage disconnect function provides a means of electrically isolating hazardous voltage within a battery pack from external circuitry or components without user intervention, based on some input triggering event. An automatic disconnect device should also provide a reset capability for restoring the traction voltage after the initiating condition has been cleared. Several types of events are commonly used as inputs to an automatic disconnect function.

b. *Detected Loss of Battery Isolation (Ground Fault):* It is desirable to monitor the degree of electrical isolation between traction battery voltage and vehicle conducting structures. Loss of such isolation is not in and of itself an unsafe condition; however, detection of a loss of isolation may be used to activate an automatic disconnect. If the vehicle is in operation when the loss of isolation is detected, the disconnect action should occur only in the non-motoring mode (e.g., key (power-enabling device) off, key removed, or in park).

c. *Hazardous Voltage Interlock Loop (HVIL):* The general intent of a HVIL is to monitor the integrity of a loop where hazardous voltage is present which could expose persons to potentially hazardous voltage if opened or disconnected. In general, the response to loss of continuity in a HVIL should be to actuate an automatic hazardous voltage disconnect.

d. *Overcurrent:* In addition to other functions as described in the preceding sections, an automatic disconnect device may be used to perform either a primary or secondary/redundant overcurrent protection function. If some other device acts as the primary overcurrent protection means, it may also be desirable to actuate the automatic disconnect device in the event of an overcurrent condition, either to perform its disconnect function or to provide more accurate overcurrent protection.

e. *Manual Disconnects*: A manual disconnect can provide manually operated hazardous voltage electrical isolation for vehicle assembly, service, and maintenance operations. Opening a manual disconnect should remove any voltage between positive and negative battery pack output terminals.

f. *Special Tools*: Disassembly of the propulsion and control systems is not recommended unless specific maintenance is warranted. Any disassembly and/or troubleshooting should be done with properly trained personnel supervising each specific exercise. Personnel Protective Equipment (PPE) appropriate for the expected voltage level should be used and will include insulated rubber gloves and leather covers rated for at least 1000 VDC, tools and CAT III-IV electrical multi-meters and leads rated for at least 1000 VDC. The vehicle’s 12 and/or 24 VDC

batteries should also be disconnected prior to any high voltage measurements and/or maintenance. A procedure for isolating/de-activating the high voltage components should be provided by the vehicle manufacturer. These procedures should be verified during the initial inspection and new equipment training before any maintenance or disassembly is started.

g. *Grounding:* If hazardous voltages are contained within a conductive exterior case or enclosure that may be exposed to human contact as installed in the vehicle, this case should be provided with a conductive connection to the vehicle chassis. Energy storage components (i.e., batteries) and major power electronics components should have their external conductive cases connected directly to the vehicle conductive structure (chassis) by a ground strap, wire, welded connection or other suitable low-resistance mechanical connection. Case ground connectors routed from other components should be connected to this grounding means. Other components which receive hazardous voltages from sources outside their conductive enclosures may have their cases grounded either directly as previously stated or indirectly through the wiring harness which carries the voltage(s) from the external source. The intent of this guideline is that disconnecting a wiring harness used to provide indirect case grounding should also disconnect the source of hazardous voltages.

h. *Fusing:* Fuses are protective devices designed to interrupt the electrical circuit when subjected to excessive current. They are nonreversible and must be replaced after the circuit malfunction is corrected. They should not be used as personnel protection devices, since they do not respond sensitively enough to protect persons from injury due to contact with hazardous high voltage.

4.4 Center of Gravity (CG).

Determine the location of the vehicle's center of gravity IAW TOP 2-2-800[12]. ITOP 2-2-800(1)[13] is used for tracked vehicles.

This test and associated measurements are useful for hybrid vehicles that have been developed/modified from existing platforms. Hybrid electric drive conversions result in the replacement and/or relocation of major driveline components. Quite often the primary engine is replaced with a unit of much smaller displacement, and because there is often not a mechanical link to the driving wheels, the engine may end up in an unconventional location. Multi-speed transmissions and transfer cases are generally not needed. The addition of multiple cooling system loops, traction motor(s), batteries, and control systems are all added necessities of the hybrid conversion.

For comparison purposes a curb weight configuration is recommended. The impact of the driveline reconfiguration and secondary energy component locations can be assessed directly. Center of gravity location directly impacts vehicle performance characteristics such as on/off road handling, braking, gradeability and obstacle negotiation.

Once the curb weight configuration is quantified, the impacts of on-vehicle equipment (e.g., radios, tools etc) can be assessed. If a fixed payload is considered mission essential, its impact on the final center of gravity can be assessed. If a reduction in payload is required to reduce axle, wheel or tire overload conditions, the "new" vehicle configuration should be negotiated with the user, customer, and analyst.

4.5 Weight Distribution.

Determine the weight distribution and ground pressure characteristics of the test vehicle IAW TOP 2-2-801[14]. ITOP 2-2-801(1)[15] is used for tracked vehicles.

Converted hybrid vehicles often weigh significantly more than their conventional counterparts. Any deviation from the chassis specified axle, wheel or tire loading should be documented. Appropriate speed reduction and/or tire inflation pressure increases may be used to offset the weight increase. If changes are adopted, inspection procedures should be developed to watch for potential chassis, suspension and tire/wheel safety problems. More frequent inspections and/or additional instrumentation to measure structural integrity and fatigue may be necessary.

4.6 Acceleration, Maximum and Minimum Speeds.

Conduct testing to determine full throttle acceleration characteristics and maximum and minimum speed capabilities IAW TOP 2-2-602[16]. ITOP 2-2-602(1)[17] is used for tracked vehicles.

4.7 Dynamic Stability, Handling and Steering.

Determine the vehicle rollover limit and steering and handling characteristics IAW TOP 2-2-002[18]. ITOP 2-2-609(1)[19] is used for tracked vehicles.

4.8 Fuel Consumption.

Determine the fuel consumption characteristics (no load, road load, full load, and when operating over specified test courses) of the test vehicle IAW TOP 2-2-603[20]. ITOP 2-2-603(1)[21] is used for tracked vehicles.

Fuel consumption should be measured at multiple states of charge for each test. Specific definitions of descriptors like high and low SOC will need detailed clarification for each test conducted. If a quantitative value can be determined from a battery capacity measurement, for example, then that value should be used in lieu of a qualitative descriptor. The hybrid vehicle may have significantly different fuel consumption characteristics depending on the vehicle’s initial SOC and the duty cycle (test course) selected. Also, stationary fuel consumption should be considered for hybrid vehicles having an export power capability.

4.9 Gradeability and Side Slopes.

Determine vehicle performance capabilities during operations on maximum specified longitudinal grades and side slopes IAW TOP 2-2-610[22]. ITOP 2-2-610(1)[23] is used for tracked vehicles.

It is important to operate the hybrid vehicle in all potential operating conditions while on these extreme mobility challenges. Testing should be conducted at high and low states of charge. Specific definitions of descriptors like high and low SOC will need detailed clarification for each test conducted. If a quantitative value can be determined from a battery capacity measurement, for example, then that value should be used in lieu of a qualitative descriptor. Low speed and sustained speed operations should also be investigated. Quite often, hybrid designs cannot accommodate the low speed - high torque requirements when climbing extreme grades. At high SOC the internal combustion engine may not operate and performance will be degraded until battery and generator limits are reached.

4.10 Standard Obstacles.

Determine the ability of the vehicle to negotiate various standard obstacles IAW TOP 2-2-611[24]. ITOP 2-2-611(1)[25] is used for tracked vehicles.

It is important to operate the hybrid vehicle in all potential operating conditions while negotiating extreme mobility challenges. Testing should be conducted at high and low states of charge. Specific definitions of descriptors like high and low SOC will need detailed clarification for each test conducted. If a quantitative value can be determined from a battery capacity measurement, for example, then that value should be used in lieu of a qualitative descriptor. Quite often, hybrid designs cannot accommodate the low speed - high torque requirements when climbing obstacles. At high SOC the internal combustion engine may not operate and performance will be degraded until battery and generator limits are reached.

4.11 Security from Detection.

When required, conduct testing to determine security from detection characteristics IAW TOP 2-2-615[26].

Hybrid vehicles equipped with a silent run capability should be considered for testing. Thermal signature testing should also be considered. Vehicles equipped with traction batteries will need to be operated for a significant period of time at low SOC to insure an adequate increase in battery temperature. The actual time period and duty cycle will be design dependent and should be negotiated during the test-planning phase.

4.12 Towing Resistance.

Vehicle power losses due to suspension and running gear should be measured by conducting tests IAW TOP 2-2-605[27]. ITOP 2-2-605(1)[28] is used for tracked vehicles.

Prior to towing any hybrid electric vehicle, the driveline design must be well understood. Generally, the vehicle will have specialized towing procedures and/or speed limits associated with flat towing. Potential damage to the traction motors, generator, controllers and/or batteries may result if proper procedures are not followed.

4.13 Drawbar Pull.

Determine vehicle drawbar pull characteristics IAW TOP 2-2-604[29]. ITOP 2-2-604(3)[30] is used for tracked vehicles.

Drawbar pull tests should be conducted at various initial SOC values, including at least one high and one low SOC. Specific definitions of descriptors like high and low SOC will need detailed clarification for each test conducted. If a quantitative value can be determined from a battery capacity measurement, for example, then that value should be used in lieu of a qualitative descriptor. Vehicle performance will be significantly different depending on the contribution of traction batteries. During each sustained test speed selected, the ground speed should be held long enough to capture the peak and sustained performance. The ability of the power electronics and battery/motor controllers to maintain high-sustained current draw are often time limited. The dynamometer operator and test engineers should be aware of this and monitor driveline temperatures closely to prevent damage.

4.14 Braking.

Determine the test vehicle's braking capability for the test scenarios specified IAW TOP 2-2-608[31]. TOP 2-2-627[32] is used for tracked vehicles.

Performance brake testing should be conducted at high and low states of charge. Specific definitions of descriptors like high and low SOC will need detailed clarification for each test conducted. If a quantitative value can be determined from a battery capacity measurement, for example, then that value should be used in lieu of a qualitative descriptor. At high SOC, regenerative braking may not function due to the battery capacity. At lower SOC, energy recovery may be limited by battery health and/or chemistry, etc. The controller/inverter shall limit the minimum traction battery discharge voltage to prevent degradation of battery life, and should limit the maximum regeneration voltage to prevent external gassing of the batteries. Suppliers should specify the voltage limits and describe how these limits are implemented prior to testing.

Operational testing should be conducted where sufficient elevation changes are present so as to provide a need for repetitive brake applications. Sufficient data are required to conduct an energy balance of the engine - generator, traction motors and traction batteries.

4.15 Soft Soil Mobility.

Determine the capability of the test vehicle to operate through various soft soil conditions IAW TOP 2-2-619[33]. ITOP 2-2-619(1)[34] is used for tracked vehicles.

4.16 Fording.

Determine the shallow water fording capability of the test vehicle IAW TOP 2-2-612[35]. ITOP 2-2-612(1)[36] is used for tracked vehicles.

Prior to fording a hybrid vehicle, a detailed inspection of the high voltage cables, compartments, and electrical components should be conducted. Evidence of water/sediment intrusion and corrosion should be documented. Vehicle specific procedures will require development to insure safe operations entering and exiting the fording obstacle. Specific attention should be given to those components at or below the water line. The vehicle design should be mature enough to handle typical off-road water type obstacles (pot holes) as well as splash events. A quantitative evaluation of this performance should be conducted using degraded primary road and secondary road test courses prior to conducting fording events.

A means of monitoring battery isolation and ground fault protection should be established as part of the test planning process. The criteria for battery and electrical component isolation specified in SAE J1766, Recommended Practice for Electric and Hybrid Electric Vehicle Battery Systems Crash Integrity Testing, and U.S. Department of Transportation National Highway Traffic Safety Administration Laboratory Test Procedure TP 305-00 Electric Powered Vehicles: Electrolyte Spillage and Electrical Shock Protection, should be adhered to for fording events.

Isolation of the traction battery system should be measured IAW U.S. Department of Transportation National Highway Traffic Safety Administration Laboratory Test Procedure TP 305-00 Electric Powered Vehicles: Electrolyte Spillage and Electrical Shock Protection. This procedure was developed to evaluate the integrity of high-powered electrical system crashworthiness. The baseline measurements outlined in section 8.3 provide a means for measuring and evaluating the electrical isolation characteristics of high voltage power sources.

4.17 Swimming.

If required, determine vehicle performance capabilities during operations in bodies of deep water IAW TOP 2-2-501[37]. ITOP 2-2-501(1)[38] is used for tracked vehicles. The vehicle inspection procedures, pre-test evaluation of performance, and means of monitoring battery isolation and ground fault protection presented in paragraph 4.16, Fording, should be utilized prior to swim testing.

4.18 Electromagnetic Interference Testing.

Test vehicle and subsystems for interference levels IAW TOP 2-2-613[39].

Tests should be conducted at high and low states of charge to insure adequate traction battery activity during the testing. Specific definitions of descriptors like high and low SOC will need detailed clarification for each test conducted. If a quantitative value can be determined from a battery capacity measurement, for example, then that value should be used in lieu of a qualitative descriptor.

4.19 Cooling Systems.

Conduct full-and part-throttle vehicle operations to determine the cooling characteristics of the engine, power train, and auxiliary components when exposed to high-temperature environments IAW TOP 2-2-607[40]. ITOP 2-2-607(1)[41] is used for tracked vehicles.

Hybrid electric vehicles often employ much more complicated cooling systems than conventional powered vehicles. The motor generator, traction motors, controllers and batteries all require active cooling to maintain their sustained operating characteristics. As a result, multiple coolant pumps, heat exchangers and coolant types can be employed on a single chassis. The use of stacked and/or split heat exchangers often need additional temperature grid measurements. Coolant temperatures to/from critical driveline components and their controllers require extensive knowledge of the vehicle. As part of the test planning process, a detailed instrumentation list should be developed. Significant disassembly of the vehicle is necessary in order to instrument heat exchangers, battery packs and motor controllers. Access to the vehicle during the build process can reduce/eliminate that disassembly process.

Particular attention to lead wire shielding and grounding requires consideration as thermocouples are low power transducers and are often affected by the high voltage/current environment of a hybrid electric vehicle. Alternative temperature measuring transducers, e.g., thermistors, should be considered when thermocouples are impractical.

4.20 Endurance.

Determine the test vehicles ability to operate over terrains of varying severity for prescribed lengths of time or distance IAW TOP 2-2-506[42]. ITOP 2-2-506(1)[43] is used for tracked vehicles.

4.21 High and Low Temperature Tests.

Determine the performance of the test vehicle during operations in extreme temperature environments IAW TOP 2-2-816[44]. ITOP 2-2-816(1)[45] is used for tracked vehicles.

5. DATA REQUIRED.

Data required are specified in the pertinent TOPs and ITOPs.

6. PRESENTATION OF DATA.

Methods for presentation of data are specified in the pertinent TOPs and ITOPs.

APPENDIX A. CHECKLISTS

I. MECHANICAL HAZARD CHECKLIST

This checklist may be used as a guide for evaluating mechanical hazards when testing vehicles and their equipment.

Yes	No	NA	
			1. Is the equipment designed so that the center of gravity, configuration or location of legs and supports make the equipment unlikely to tip over from unbalance effect or strong wind?
			2. Are expandable and collapsible structures such as shelters, jacks, supports, masts, tripods, etc., free from projections, sharp edges or design features which might be hazardous to personnel or associated equipment?
			3. Are lifting rings or slings provided for equipment which is normally moved or lifted by machine?
			4. Are ladders, climbing rings, handholds, rails, walkways, etc., provided where needed?
			5. Are steps and ladders and methods of supporting them safely made?
			6. Are entrances to equipment shelters free of hazardous obstructions?
			7. Do floor surfaces provide adequate nonslip characteristics?
			8. Are fasteners and methods of securing equipment to walls and racks sufficiently strong to prevent breakaway and falling?
			9. Can equipment shelters mounted on vehicles be entered without encountering a hazard?
			10. Does the installation of equipment on vehicles provide sufficient mechanical strength to minimize potential safety hazards?
			11. Are provisions made in vehicular and shelter installations for securing equipment, tools and accessories during movement?
			12. Are safety measures provided in the event the trailer becomes detached from the towing vehicle?

Yes	No	NA	
			13. When semi-trailers are detached from towing vehicles, do dolly wheels or landing gear provide adequate support?
			14. If a standard military vehicle has been modified to accommodate the equipment, is the vehicle still capable of satisfactory and safe operations?
			15. Do doors and hinged covers have positive-action hold-open devices?
			16. Are locking mechanisms for doors and drawers designed to prevent injury to the operator when the lock is released?
			17. Are limit stops provided on roll-out racks and drawers?
			18. Are there provisions for easily overriding limit stops on roll-out racks and drawers?
			19. Is the method of opening a cover evident from the construction of the cover? If not, is an instruction plate permanently attached to the outside of the cover?
			20. Is it evident when a cover is in place but not secured?
			21. Is the equipment provided with suitable carrying handles?
			22. Are handles recessed rather then extended where they might be hazardous?
			23. Are handles positioned so they cannot catch on other units, wiring, or protrusions?
			24. Are handles located over center of gravity whenever possible?
			25. Are doors and other openings free of hazards from improperly designed catches, hinges, supports, fasteners and stops?
			26. Are components placed to allow sufficient space for use of test equipment and tools?
			27. Are heavy parts located as close as possible to load-bearing structures and as low as possible?
			28. Is the weight distribution such that the equipment is easy to handle, move or position?

Yes	No	NA	
			29. Are tasks of operation and maintenance such that they do not require excessive physical strength?
			30. When the equipment is to be manpacked, are the weight and configuration such that the combat effectiveness of the test soldier is not jeopardized?
			31. Is the equipment free of sharp or overhanging edges and corners that might cause injury to personnel?
			32. When glass is used, is it glareproof and shatterproof?
			33. Do exposed gears, cams, levers, fans, belts or other reciprocating, rotating or moving parts have adequate safety covers?
			34. Is the equipment provided with sufficient caution plates to warn maintenance personnel of potential safety hazards?
			35. Are warning signs coded and colored in accordance with Army regulations?
			36. When required, are provisions made for protection against eye hazards from flying particles?
			37. Are safety valves, relief valves or other safety devices adjusted to the proper setting?
			38. Are potential mechanical hazards adequately treated in the instructional manual?

II. ELECTRICAL HAZARD CHECKLIST

This checklist may be used as a guide for evaluating electrical or electronic hazards when testing vehicles and their equipment.

Yes	No	NA	
			1. Is the path to ground from the equipment continuous and permanent?
			2. Does the grounding system have sufficient mechanical strength to minimize the possibility of accidental ground disconnection?

Yes	No	NA	
			3. Is the ground connection to the chassis or frame mechanically secured by one of the following methods? a. Secured to a spot-welded terminal lug. b. Secured to a portion of the chassis or frame that has been formed into a soldering lug. c. Secured by a screw or nut and a lockwasher to a terminal on the ground wire.
			4. Is the grounding system of sufficient gauge size to safely conduct any currents that may be imposed upon it?
			5. Is the impedance of the ground system sufficiently low to limit the potential above ground and to facilitate the operation of the overcurrent devices in the circuits?
			6. Are ground connections to shields and other mechanical parts, except the chassis and frame, made independently of the electrical circuits?
			7. Do plugs and convenience outlets for use with portable tools and equipment have provisions for automatic grounding?
			8. Are all external metal parts, control shafts, bushings and shields at ground potential at all times?
			9. Are voltages properly marked?
			10. Are guards, safety covers and warning plates provided for items handling 70 to 500 volts rms or dc?
			11. Are built-in test points provided where measurements of potentials greater than or equal to 300 volts peak?
			12. Can high-voltage circuits and capacitors be discharged to 30 volts within 2 seconds or less by automatic protective devices?
			13. When equipment is designed to operate on more than one type input power, are adequate precautions taken to prevent connection of improper power?
			14. Are dc power connections clearly marked for polarity?
			15. Are adjustment screws or other commonly worked-on parts located away from unprotected high voltages?

Yes	No	NA	
			16. Are tools to be used near high voltages adequately insulated?
			17. Do meters have protection against high voltage or current at the terminals?
			18. Are compartments operating at potentials in excess of 500 volts rms or dc, where access is required for adjustment purposes, equipped with interlocks with by-pass devices which remove all potentials in excess of 30 volts rms or dc?
			19. In compartments where access into the interior is required for adjustment purposes and no interlocks are used, are voltage in excess of 70 volts rms or dc isolated with barriers or guards?
			20. Is the grounding conductor of the equipment electrically insulated from the ac power return (neutral) within the system and/or equipment?
			21. Are mechanical and electrical interlocks designed to prevent energizing by movement when men are in positions where it could be dangerous?
			22. Are internal controls located at safe distances from dangerous voltages?
			23. Are physically similar but electrically noninterchangeable components keyed so that it is impossible to insert a wrong unit?
			24. Where design considerations require plugs and receptacles of similar configuration, are mating plugs and receptacles suitably coded and marked?
			25. Is shielding sufficiently separated from exposed conductors to prevent shorting or arcing?
			26. Are wires and cables adequately supported and terminated to prevent shock and fire hazard?
			27. Are wires and cable properly protected at points where they pass through metal partitions?
			28. Can maintenance be accomplished with shielding in place?
			29. Do floor surfaces provide adequate insulating characteristics?
			30. Are emergency controls placed in readily accessible positions?
			31. Is the main power breaker in an easily accessible location?
			32. Does the main power breaker cut off all power to the complete equipment or system?

Yes	No	NA	
			33. Can the power be cut off while installing, replacing or interchanging a complete equipment, assembly or part thereof?
			34. Are safety switches provided which will deactivate associated mechanical drive units without disconnecting other parts of the equipment?
			35. Are remotely located assemblies provided with safety switches to allow independent disconnection of the equipment?
			36. Are potential electrical hazards adequately treated in the instruction manual?
			37. Are disconnect devices (circuit breakers) properly labeled?

III. CHEMICAL HAZARD CHECKLIST

This checklist may be used as a guide when testing vehicles and their equipment which use chemicals.

Yes	No	NA	
			1. Has each chemical used in or with the system been identified in the safety statement?
			2. Have approved time-concentration exposure limits been established for each chemical used? If not, are toxicity tests being performed and interim safety precautions provided by the Surgeon General?
			3. Has each condition necessary for exposure to personnel or release to atmosphere or water been evaluated?
			4. Are the time-concentration exposure limits to personnel exceeded during operation of the item?
			5. Are precautions made to prevent exposure to respiratory hazards adequate? Skin absorption? Ingestion?
			6. Have all possible chemical reactions between the materials involved been analyzed including those with materials used in conjunction with the item being tested?
			7. Are operator means of detecting a hazardous condition adequate?
			8. Are all harmful chemicals properly identified with appropriate caution notices?

Yes	No	NA	
			9. Are adequate safety devices and safety instruction provided for handling and use of gases stored under high pressure and/or extremely low temperature?
			10. Has the effect of decontamination procedures on the equipment surface been studied? Is chemical or biological material retained in the pain or material? What is the desorption rate?
			11. Did any personnel suffer irritation dermatitis as a result of contact with the chemical materials?
			12. Are air intakes isolated from the exhaust?
			13. Are adequate oxygen levels maintained inside shelters, etc.?
			14. Is the collective efficiency of material collection equipment (scrubbers, filters, incinerators) adequate to prevent hazardous conditions?
			15. Are the safeguards in event of power outage adequate?
			16. Are adequate disposal procedures provided for all chemicals used as a part of or with the item?

IV. PHYSIOLOGICAL HAZARDS CHECKLIST

Yes	No	NA	
			1. Is the ambient noise level acceptable for personnel safety and efficiency?
			2. Have all physical operator stresses such as repetitive motions, awkward working conditions, and vibration been evaluated?
			3. Have all mental demands on operators been evaluated?
			4. Have all lifting and carrying requirements been evaluated?
			5. When necessary, have all ear- and eye-protection devices been provided?
			6. Are adequate control and warning signs included to prevent exposure in excess of standards to ionizing radiation?
			7. Are adequate controls and warning signs included to prevent exposure in excess of standards to nonionizing radiation, including UV, IR, laser, and microwave?

Yes	No	NA	
			8. Are adequate illumination levels available for the tasks required?
			9. Has heat stress to personnel as the result of exposure to high temperature or wearing protective equipment been evaluated?
			10. Does the ventilating system provided for operator safety by ducting excess heat liberated by equipment to the outside of the shelter?
			11. Is equipment-cooling air for shelter-mounted equipment completely separated from the personnel space to prevent contamination of the surrounding air?
			12. Are adequate precautions made to prevent exposure of personnel to respiratory hazards from toxic gases, ducts, fumes and mists?
			13. Is the air intake isolated from the exhaust?
			14. Is the shelter heating and ventilating system designed to safeguard against depletion of oxygen in the personnel area?
			15. Are all air-flow paths free of obstruction?
			16. Is shelter-mounted equipment furnished with test kits for checking air contamination and oxygen depletion?
			17. Are acids or other harmful liquids properly identified with appropriate caution notices?
			18. Do instructions specify type of cleaning fluid and precautions to be taken when cleaning equipment?
			19. Are adequate safety devices and safety instructions provided for handling and use of gases stored under high pressure and/or extreme temperatures, e.g., hydrogen, helium, oxygen, nitrogen?
			20. Is protection provided against hot surfaces which might be dangerous to personnel?

V. FIRE AND EXPLOSION HAZARD CHECKLIST

Yes	No	NA	
			1. Have all possible ignition sources been evaluated to determine potential hazards?
			2. Has the flammability of the materials been taken into account in planning for use of the item?
			3. Are fire extinguishers of the proper type for the equipment provided and mounted in easily accessible locations?
			4. Are properly marked fire exits provided in shelters when required?
			5. Have precautions been taken to assure that the storage and distribution of flammable material are done safely?
			6. Is a self-closing metal can provided for oil rags and waste where required?
			7. Have fire-extinguishing methods been included in technical publications?

APPENDIX B. HYBRID SPECIFIC VEHICLE CHARACTERISTICS

TRACTION BATTERY CHARACTERISTICS (referenced to 25˚C)
Manufacturer____________________
Model ____________________
Type ____________________
Description ____________________
Number of Batteries in the Pack____________________
Arrangement (series or parallel) ____________________
Battery module voltage (VDC)____________________
Battery pack voltage (VDC) ____________________
Battery module weight (kg) ____________________
Battery pack weight (kg)____________________
Maximum normal gassing rate (scfm or cc/ml/m) ____________________
Maximum abnormal gassing rate (scfm or cc/ml/m) ____________________
Battery capacity to 100% Manufacturer's DOD, 1 hour rating (Ah) ____________________
Battery capacity to 100% Manufacturer's DOD, 2 hour rating (Ah) ____________________
Battery capacity to 100% Manufacturer's DOD, 3 hour rating (Ah) ____________________
Battery energy to 100% Manufacturer's DOD, 1 hour rating (Wh)____________________
Battery energy to 100% Manufacturer's DOD, 2 hour rating (Wh)____________________
Battery energy to 100% Manufacturer's DOD, 3 hour rating (Wh)____________________
Probable life of an average battery to a Manufacturer's DOD of:
50% DOD (cycles) ____________________
80% DOD (cycles) ____________________
Time required to recharge the batteries from a DOD of:
50% DOD (cycles) ____________________
80% DOD (cycles) ____________________

CHARGER CHARACTERISTICS (if used)
Manufacturer____________________
Model ____________________
UL file number ____________________
Description ____________________
Location ____________________
Charger efficiency (%) ____________________
Charger input voltages (VAC) ____________________
Charger input power factor (%) ____________________
Charger input total harmonic distortion (%)____________________
Maximum charger current output (A)____________________

TRACTION MOTOR CHARACTERISTICS
Manufacturer____________________
Model ____________________
Description ____________________
Type (AC, DC, Brushless, etc.) ____________________
Rated Efficiency ____________________ % @ ____________________kW
Operating Range (RPM)____________________

Maximum Intermittent Power__________________ kW for ________________minutes
Maximum Continuous Power____
Cooling Medium and Method____

CONTROLLER CHARACTERISTICS
Manufacturer____
Model ____
Description ____
Type and Phase____
Input Voltage Range ____
Maximum Output (A)____
Type of Power Electronics (IGBT, mosfet, etc.) ________________________________
Rated Efficiency ____________________________ % @ _______________________ A

INTERNAL COMBUSTION ENGINE CHARACTERISTICS
Model ____
Configuration ____
Displacement (liters)____
Number of Cylinders____
Power (hp@rpm) ____
Torque (lb-ft@rpm) ____
Operating Range (rpm)____
Recommended Fuel (all types) ____
Fuel Tank Capacity (liters) (specify for each fuel type)_____________________________

TRANSMISSION CHARACTERISTICS
Manufacturer____
Type ____
Model ____
Description ____
Gear Ratio(s)____

SERVICE (FOUNDATION) BRAKES
Type front ____
Type rear____
Power source, if used ____
Average power, if used (W) ____
Maximum regenerative braking (kW) ____

STEERING
Type ____
Description ____
Manufacturer____
Power source, if used ____
Average power, if used (W) ____

Reprinted in part from: EV America, Hybrid Electric Vehicle Technical Specifications, 1 November 2004.

APPENDIX C. DEFINITIONS

Active materials: The substances of a positive or negative plate that react to produce current.

Ampere-hours (A-h): The product of current in amperes multiplied by the time the current is flowing. The integration with respect to time of a specific current profile. Battery capacity is generally expressed in ampere-hours.

Aqueous Electrolyte Batteries: Batteries equipped with water-based electrolytes.

Battery: One or more cells connected to form a single unit and having provisions for external connections.

Battery Controller/Management System: Electronic components needed to provide communication between the battery pack and other vehicle components. It may also monitor and/or control other battery function (watering, temperature, electrolyte flow, etc.). It may also provide an operator interface.

*Battery Module***:** A grouping of interconnected cells in a single mechanical and electrical unit.
.

Battery Pack: Interconnected battery modules that have been configured for a specific energy storage application.

C rate: Discharge or charge current rate in amperes, numerically equal to the rated capacity of a cell or battery in ampere-hours, rated at the 1 hour discharge rate.

C_n *:* Charge or discharge current numerically equal to the capacity, rated at the n hour discharge rate.

Capacity: Ampere hours available from a fully charged cell or battery.

Capacity, available: Total capacity that may be obtained at defined charge and/or discharge rates and their associated environmental conditions.

Capacity, rated: A designation by the battery manufacturer which identifies a particular cell/battery capacity. This definition generally provides an approximation of actual capacity. Rated capacity is usually expressed in ampere-hours at a given discharge current.

Capacity, residual: Capacity remaining at a particular point in time after any set of operating conditions, usually including a partial discharge or periods of inactivity.

Cell: An assembly of at least one positive electrode, one negative electrode, and other necessary electrochemical and structural components. A cell is a self-contained energy conversion device whose function is to deliver electrical energy to an external circuit via an internal chemical process.

Charge depleting: A vehicle – duty cycle characteristic where continued operations will cause a reduction in the traction battery state of charge.

Charge, state of: Residual capacity of a cell/battery expressed in terms of a fully charged capacity.

Charge sustaining: A vehicle – duty cycle characteristic where continued operations will permit continuous vehicle operations.

Charge rate: The current at which a battery is charged, expressed as a function of the battery's rated capacity. For example, the 20 hr charge rate of a 10 A-hr would be equal to C/20 = 10/20 = 0.5 A.

Charging algorithm: The circuitry/mathematical controls used by a charger to automatically control the charging profile of current versus voltage versus time during the battery charge.

Conditioning: Maintenance procedure consisting of a deep discharge, short and constant current charge used to correct cell imbalance. Charging profiles are specific to battery chemistry and manufacturers.

Constant current: A charging method in which the current does not change in magnitude regardless of battery voltage or temperature.

Constant potential: Charging method that applies a fixed voltage to a cell or battery.

Coulombic (Ampere-Hour) Efficiency: The ampere-hours removed from a cell or battery during a discharge divided by the ampere hours required to restore the initial capacity.

Cut-off voltage: Voltage at which a discharge or charge profile is terminated.

Deep discharge: A condition in which a cell is discharged to 0.5 V or less at a low rate. A discharge resulting in a residual capacity of 20% or less.

Depth of discharge (DOD): The percentage of rated capacity to which a cell or battery is discharged.

Discharge: Withdrawal of electrical energy to endpoint voltage before the cell or battery is recharged.

Discharge voltage: The voltage of a battery during discharge.

Disconnect: A condition in which a high voltage source is electrically separated from a high voltage bus, as for example by an automatic disconnect device. Such electrical separation normally requires that both the high voltage positive and return leads be disconnected.

Duty cycle: The condition and usage to which a battery and/or vehicle is subjected during operation. A typical duty cycle consists of charge, overcharge, rest and discharge.

Electric Vehicle (EV): A vehicle powered solely by energy stored in an electrochemical device.

Electrical isolation: The electrical resistance between the vehicle high-voltage system and any vehicle conductive structure. A value greater than or equal to 500 W/V at the maximum battery pack working voltage, is defined as "isolated". Isolation is measured from both the positive and negative battery terminals relative to the vehicle conductive structure.

Electrolyte spillage: The fall, flow, or run of propulsion battery electrolyte in, on, or from the vehicle, including wetness resulting from capillary action (FMVSS 305).

Energy: Output capability determined from the measured ampere-hours capacity and the average closed-circuit voltage. Energy is generally expressed in kW-hrs.

Energy density: An expression of stored energy as a function of packaged weight and/or volume. Energy density is rate dependent.

Environmental conditions: External factors to which a cell or battery may be subjected such as temperature, humidity, altitude, solar radiation, etc. which may impact the system performance.

*Equalization***:** The process of restoring all cells in a battery or pack to approximately the same state-of charge.

Fast charging: Rapid return of energy to a battery at the C rate or greater. Also referred to as in-rush current.

Float charging: The use condition of a battery wherein the charge is maintained by a continuous long-term constant potential charge.

Full hybrid: A hybrid vehicle design that can operate using the engine only, batteries only or a combination of both.

Gassing: The liberation of hydrogen and/or oxygen gasses from a cell.

High rate discharge: Withdrawal of large currents in short time intervals, usually at a rate less than 1 hour.

High Voltage (HV): Circuit voltage of more than 50 VDC or 30 VAC.

Hybrid vehicle (HEV): A vehicle design that incorporates more than one means of energy storage or propulsion. Hybrid vehicle designs can be differentiated by the physical layout of the vehicle drivetrain, fuel type or mode(s) pf operation.

Hydraulic hybrid: A vehicle that instead of storing energy in a battery, stores energy in a pressurized accumulator and supplies that energy for propulsion through mechanical pumps and turbines.

Level 1 Charging: A charging method that allows an electric vehicle to be connected to the most common grounded receptacle (e.g., in the USA, 120 VAC Nominal, 60 Hz, 15A, 1-phase).

Level 2 Charging: A charging method that utilizes dedicated electric vehicle supply equipment in either private or public locations. In the USA, the maximum power supplied for level 2 charging is 208 or 240 VAC Nominal, 60 Hz, 40A, 1-phase or 3-phase.

Level 3 Charging: A charging method that utilizes dedicated electric vehicle supply equipment to provide DC energy from an appropriate off-vehicle charger to the electric vehicle. In the USA, the maximum power supplied for level 3 charging equipment should be in the range of 25 KW to 160 KW, 208 to 600 VAC Nominal, 60 Hz, 3-phase.

Low rate discharge: Withdrawal of small currents for long time periods, usually longer than 1 hour.

Micro hybrid: A hybrid design whose electric motor doesn't provide torque for propulsion. It acts as a starter/generator to allow the combustion engine to stop and restart quickly to avoid excessive engine idling.

Mild hybrid: A hybrid vehicle whose electric motor cannot independently provide all of the vehicle's propulsion requirements. It acts as an assist to the internal combustion engine.

Nonaqueous Electrolyte Batteries: Cells or batteries with electrolytes that are not water based, such as those with molten salts or organic electrolytes.

Open circuit voltage: The no-load voltage of a cell or battery measured with a high impedance voltmeter under constant environmental conditions.

Overcharging: Continuing charge after the battery has accepted its maximum amount of charge. In a vented cell, a result will be decomposition of water in the electrolyte into hydrogen and oxygen gasses. In a sealed cell a result will be increased cell temperature.

Overcurrent Protection Device: A fuse, circuit breaker, intelligent contactor, or other device placed in an electrical circuit to provide current overload protection.

Parallel: Term used to describe the interconnection of batteries where all of the like terminals are connected together.

Parallel hybrid vehicle: A hybrid vehicle design where the internal combustion engine can turn the drive wheels directly, either alone or in conjunction with the electric motor.

Plateau voltage: Level portion of the discharge curve, varying with discharge rate.

Plug-in hybrid electric vehicle (PHEV): PHEV is a hybrid vehicle design that can be recharged from the electrical power grid.

Power assist hybrid: A hybrid design that uses the internal combustion engine for primary power with a torque boosting electric motor also connected to a largely conventional powertrain. The electric motor, mounted between the engine and transmission, is essentially a large starter motor which operates not only when the engine needs to be started, but also when the vehicle needs additional power.

Primary cell: A cell designed to be used only once. It is not capable of being returned to its original charge state by the application of current.

Quick-charge: Charging rate that ranges from 0.2C to 0.5C rate.

Quick-charge battery: A battery that can be charged fully in 3-5 hr. using a constant current charger and is capable of continuous overcharge at this quick charge rate.

Rate: Amount of charge or discharge current expressed as a fraction or multiple of the one hour (1h) rate C.

Recharge: Return of electrical energy to a battery.

Rechargeable Energy Storage System (RESS): Rechargeable Energy Storage System (RESS) shall be a battery, capacitor, or electromechanical flywheel technology-based as defined in SAE J1711. A component or system of components that stores energy and for which its supply of energy is rechargeable by an electric motor-generator system, an off-vehicle energy source, or both.

Recombination: The chemical reaction of gases at the electrodes to form a non-gaseous product.

Regenerative braking: The conversion of braking and/or driveline energy into reusable electrical energy.

Secondary battery: A battery that is capable of repeated use by using chemical reactions that are reversible. Discharged energy may be restored by supplying electrical current to recharge the cell.

Self discharge: The spontaneous decomposition of battery materials from charged to discharged state. That rate at which a battery or cell loses service capacity when standing idle.

Series: Term used to describe the interconnection of cells or batteries in such a manner that the positive terminal of an individual cell is connected to the negative terminal of the next cell.

Series hybrid vehicle: A hybrid vehicle design where the internal combustion engine is not directly connected to the drive wheels. The internal combustion engine drives a generator which provides electricity to electric traction motors.

Slow charge: "Overnight" return of energy to a battery at 0.05C – 0.1C rates.

Split rate charge: A charging method in which a battery is charged at a high initial rate and then reduced to a lower charge rate as the battery approaches full charge.

Standby charge: A low overcharge current rate of 0.01C – 0.03C, applied continuously to a vented cell battery to maintain its capacity. Often referred to as "trickle charging".

State of charge: Residual capacity of a cell or battery expressed in terms of fully charged capacity.

Temperature, cut-off: A method of switching the charge current flowing to a battery from a fast charge to a topping charge by means of control circuitry that is controlled by battery temperature.

Topping charge: A reduced rate charge that completes (tops) the charge of a cell and can be continued in overcharge without damaging the cell/battery.

Undercharging: Applying less than the amount of current required to recharge a battery.

Voltage cut-off: A method of switching the charge current flowing to a battery from a fast charge to a topping charge by means of control circuitry that is controlled by battery voltage.

Voltage limit: In a charge-controlled battery, the limit beyond which battery potential is not permitted to rise.

Voltage-temperature cut-off: A method of switching the charge current flowing to a battery from a fast charge to a topping charge by means of control circuitry that is controlled by either battery voltage or temperature.

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Forward comments, recommended changes, or any pertinent data which may be of use in improving this publication to the following address: Test Business Management Division (TEDT-TMB), US Army Developmental Test Command, 314 Longs Corner Road Aberdeen Proving Ground, MD 21005-5055. Technical information may be obtained from the preparing activity: Automotive Test Division (TEDT-AT-AD-I), US Army Aberdeen Test Center, 400 Colleran Road, Aberdeen Proving Ground, MD 21005-5059. Additional copies can be requested through the following website: http://itops.dtc.army.mil/RequestForDocuments.aspx, or through the Defense Technical Information Center, 8725 John J. Kingman Rd., STE 0944, Fort Belvoir, VA 22060-6218. This document is identified by the accession number (AD No.) printed on the first page.